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WARM DENSE MATTER SCIENCE USING INTENSE ION BEAMS

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Frontiers in Plasma Science Town Hall Meeting
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White Paper for *Frontiers of Plasma Science Panel*

Date of Submission:	***June 19, 2015***

Indicate the primary area this white paper addresses by placing "P" in right column.
Indicate secondary area or areas by placing "S" in right column

	"P", "S"
• Plasma Atomic physics and the interface with chemistry and biology	
• Turbulence and transport	
• Interactions of plasmas and waves	
• Plasma self-organization	S
• Statistical mechanics of plasmas	P

Indicate type of presentation desired at Town Hall Meeting.

	"X"
Oral	
Poster	
Either Oral or Poster	X
Will not attend	

Title:	Warm Dense Matter Science Using Intense Ion Beams
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(Limit text to 3-pages including this form. Font Times Roman size 11.
1 page of references and 1 page of figures may also be included. *Submit in PDF format*.)

- ***Describe the research frontier* and importance of the scientific challenge.**

Recent community reports have identified exciting scientific opportunities for using ion beams to advance the field of High Energy Density (HED) Science. A general question that was identified in the 2009 FESAC report "On Advancing the Science of High Energy Density Laboratory Plasmas" is: **"How are intense charged-particle beams transported in and how does their energy couple to HED plasmas?"** The 2010 "Basic Research Needs for High Energy Density Laboratory Physics" Workshop Report asked, **"what are the material and transport properties"** in warm dense matter? (Warm dense matter, or "WDM," is in a regime with density of order solid density and temperature of order an eV.)

The categories below indicate research areas that address aspects of these questions.

- Ion dE/dx in heated material is central to fusion ignition but studies in laboratory experiments are limited. How does ion-stopping change in heated material? Alpha energy deposition (at ~ 3.5 MeV) is a key step for ignition self-heating in DT fusion plasmas.

- Hydrodynamic coupling induced by volumetric (ion beam) energy deposition is different from laser surface heating and has yet to be studied thoroughly. Specifically, can energy deposition be controlled by tailoring ion-beam intensity and velocity profiles so as to optimize the shock strengths in targets relevant to heavy ion fusion energy? What is the physics of shock wave generation in tamped direct-drive targets?

- Conductivity in hot matter can be studied in ion-heated targets with measurements of thermal diffusion times. How does conductivity change in heated, magnetized matter?

Recent advances in ion acceleration have opened up opportunities for the study of WDM properties, and the study of the interaction of ion beams with matter in a warm dense state. Experiments using intense ion beams will yield basic science information and have broad application to topics such as planetary science and inertial fusion energy (IFE), including heavy ion fusion (HIF).

- ***Describe the approach to advancing the frontier and indicate if new research tools or capabilities are required.***

Ion beams may be produced using traditional accelerators or by other means such as through the target normal sheath acceleration process using lasers [see e.g., Ref. 1]. Ion beams for warm dense matter generation offer several attractive aspects, including spatially uniform and volumetric energy deposition over diagnosable large material volumes (~100 microns in radius by a few to tens of microns in depth) for any material or surface; the ability to do energy accounting by measuring the transmitted beam; and high shot rates (~1/minute). Accelerator-created ion beams further allow precise control over energy deposition with an intrinsic energy spread of a few percent; a small shot-to-shot variation in energy and intensity; a benign environment for diagnostics (low debris and radiation background) in an open (non-clean room) environment; energy deposition that leaves the target in local thermodynamic equilibrium; and small beam-induced magnetic fields.

One facility that is well suited to perform such HED science experiments is the Neutralized Drift Compression Experiment II (NDCX-II) at Lawrence Berkeley National Laboratory. The general approach is to heat planar foils of solid or foam materials with the NDCX-II helium ion beam and make measurements of the target response to the beam heating and/or measurements of the transmitted beam. The diagnostics include pyrometers, polarimeters, VISAR, streak cameras, energy analyzers, and activation plates, using equipment developed for previous experiments. Other possible diagnostics include X-ray absorption, scattering, and imaging; these would further enrich the comparison of measurements with data. The experiments can be designed and modeled using hydrodynamic codes, such as HYDRA, DISH, and ALE-AMR, as well as molecular dynamics codes and other specialized codes depending on the experiment.

Experiments can be carried out that investigate the three broad science areas discussed above:

Ion dE/dX in heated materials: Beam energy deposition in heated thin foils using an electrostatic energy analyzer that measures the energy of the transmitted ions can also be measured. Additional experiments that observe fusion neutrons from a beam-heated CD_2 deuterated plastic target could also be carried out. Helium beam ions produce ~100 kV recoil D ions, which can then interact with another D in the target. Neutrons from fusion reactions are sensitive probes of dE/dx for knock-on D ions. dE/dx can also be used as a line density diagnostic.

Hydrodynamics from volumetric energy deposition: The characteristics of rarefaction waves in ion heated metallic foils and foams (for EOS and hydrodynamic studies relevant to initial stages of IFE targets) via pyrometry, imaging, VISAR, and/or X-ray imaging diagnostics can be measured. In thicker foils, shock enhancement by rapidly increasing the ion beam energy during one ion pulse can be measured, yielding deposition that follows a shock front and enhances shock pressure, a technique proposed for HIF. Using a two-component foil, the shock from a tamper and the shock from the "end-of-range" will be measured; the relative thicknesses of the two components will be adjusted to maximize shock strength, and comparison will be made with simulations relevant to tamped direct drive targets for HIF.

Conductivity in hot matter: Target temperatures and heat conductivity can be measured using precision pyrometry. Experiments in which the ion range is shorter than the foil thickness (with steps of varying thicknesses) will allow measurement of the breakout time (and thus thermal conductivity) with and without imposed magnetic fields. Finally, one can measure the magnetic-field penetration through an ion-heated conductor with the goal of measuring thermal effects on the electrical conductivity of the dense plasma. Another possible experiment would involve measuring target response to a wobbling beam, allowing characterization of target temperature and ablation velocity from a beam that rapidly oscillates, yielding additional information about the thermal conductivity.

These topics represent a small subset of possible ion-beam-driven experiments on NDCX-II. Other related areas of investigation include material defect dynamic studies; phase transition (solid-solid, solid-liquid, and liquid-vapor); metal to insulator and insulator to metal transitions; opacity transitions (such as from transparent to opaque); fragmentation/fracture mechanics for materials under extreme conditions; droplet formation and surface tension; unusual plasma configurations such positive/negative plasmas (with low electron concentrations, and intense beam (non-neutral plasma) dynamics. Many of these topics are included in other white papers.

- ***Describe the impact of this research on plasma science and related disciplines and any potential for societal benefit*.**

These experiments have the potential for impacting inertial confinement fusion and planetary physics directly as discussed above. NDCX-II has just recently been constructed and commissioned, and the availability for science experiments will be high. Future experiments in Germany using the FAIR accelerator, and in China using the HIAF facility are several years away, leaving NDCX-II as the only accelerator-based ion heating experiments currently envisioned in the near-term. These experiments allow the U.S. to participate in a worldwide community of HED science using a variety of drivers, including X-rays (such at the LCLS), laser, laser produced ions, as well as accelerator-based ions, with their unique characteristics.

References (Maximum 1 page)

1. T. Schenkel, Arun Persaud, Qing Ji, Sven Steinke, Eric Esarey, Wim Leemans, John J. Barnard, Alex Friedman, "Extreme chemistry and properties of warm dense matter," White Paper, this meeting (2015).

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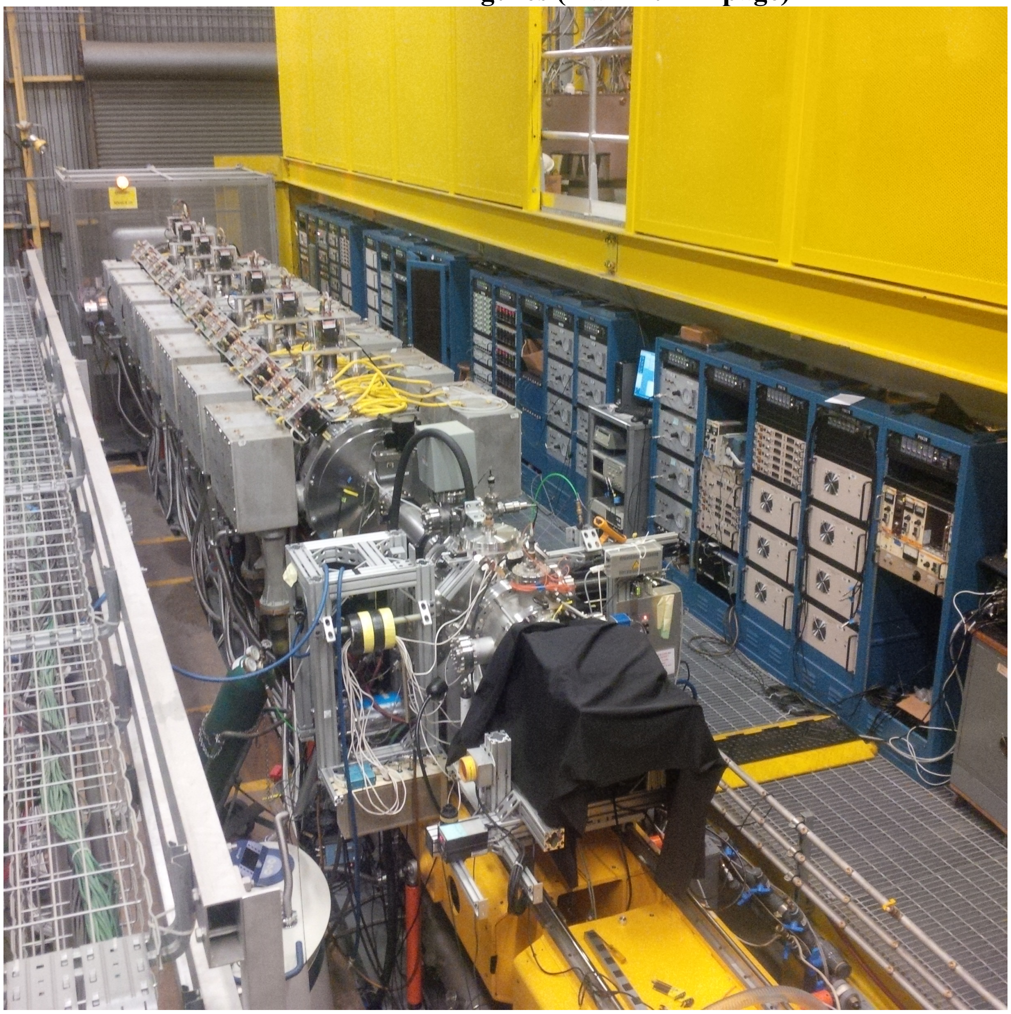
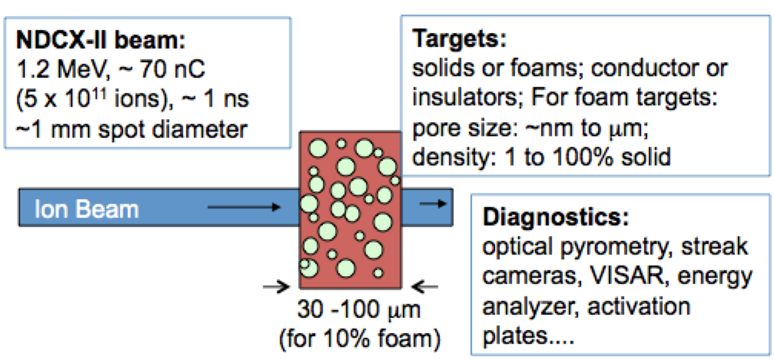
Figures (maximum 1 page)



NDCX-II accelerator at LBNL.



Parameters for WDM and beam interaction experiments on NDCX-II.